International Energy Agency Cooperative Agreement on Environmental, Safety, and Economic Aspects of Fusion Power
Minutes of the 5th Specialists Meeting on Component Failure Rate Data
IEA ESE/FP Task 5, Failure Rate Database
Culham Science Centre
April 5-6, 2005

Neill Taylor opened the meeting with his greetings and welcome to Culham Science Centre. He reminded the attendees of fire safety precautions and security pass requirements, and then the meeting proceeded.

Lee Cadwallader presented some news from the IEA-ESE/FP Executive Committee (ExCo) meeting held on September 22, 2004, during the 22nd Symposium on Fusion Technology in Venice, Italy, and some more recent news from the IEA Fusion Power Coordinating Committee (FPCC) meeting that was held in Paris on March 22, 2005. In summary, Dr. David Jackson (Canada) of the IEA-ESE/FP ExCo accepted a position to serve as a liaison between the FPCC and the ExCo. Dr. Werner Gulden was re-elected for another 2-year term as the Chair of the ExCo. Both the ExCo and the FPCC are pleased with the progress being made in the IEA-ESE.FP tasks and encourage us to make our work known to political leaders so that they understand and appreciate the progress that has been made and the collaborative nature of the work. The FPCC expects that when the ITER project becomes more active, after site selection, the ITER International Team (IT) will direct work that is solely ITER support. With the ITER IT directing work then the IEA FPCC will alter tasks to dwell mainly on future experiments rather than ITER. Attention was called to the fact that Task 5 has been labeled as useful to ITER, ITER support facilities, and future experiments, so this task will continue under the IEA agreement.

The next presentation was prepared by Dr. Toshihiko Yamanishi of the Tritium Process Laboratory (TPL) at the Tokai complex of the Japan Atomic Energy Research Institute. Lee Cadwallader gave the presentation for Dr. Yamanishi, the Japan representative for this task, who was unable to travel to England for this meeting. The presentation contained an overview of the TPL and some of the facility operating data, including annual tritium releases (which have been very low, usually < 1 Curie/a). The component failure rate data given in this presentation have been updated for an additional ~6 months of operating time and also a few clerical errors that were made during preparation of the previous conference paper were corrected. The reported data vary from the data values that were presented at the TRITIUM 2001 conference [1]; many of the new values were on the order of ~10% smaller failure rates.

Lee Cadwallader presented some information of task participants that were not able to attend the meeting. Most notably, Dr. Mohamed Eid (CEA-Saclay) sent a brief description of some of his recent work regarding reliability modeling of piping and vessels for fast fission reactors and fusion reactors. That information is attached as part of the meeting minutes.

Tonio Pinna described two areas of his recent work. The first area is occupational radiation exposure (ORE) assessment of the JET facility. The second area is his work to analyze JET operating experience data. The goal of the ORE work is to develop a model that can predict the worker radiation exposure as a function of the tasks to be performed near the ITER machine. ORE work has been requested by the French licensing agency. There was a question if Tore Supra has provided their operating experience data to the French regulators; Tonio does not know if the Tore Supra staff has given data to the CEA personnel who are working on ITER safety, he has worked mainly with JET and TFTR data since these machines have burned tritium and they are very applicable to ITER. Tonio thought that perhaps Cadarache staff are compiling the Tore Supra ORE data themselves. An interesting result of the ORE work is that while the expectation was that most of the doses had occurred during the machine shutdown periods (similar to fission reactors), the data show that workers have been receiving doses while performing activities during operating campaigns (e.g., hands-on work with diagnostic devices, vacuum leaks, etc., during weekends and backshifts). The ORE is more evenly spread over a year than lumped into long-term machine outages. The ex-vessel dose rates are between 0.1 and 3% of the in-vessel dose rates. The worker dose from tritium that has been used in tritium operations was not significant; the tritium dose accounted for only 6% of the overall worker dose in the highest tritium dose year. Tonio has presented a paper on the results of this ORE study at the recent SOFT conference [2], and the interest in the work also motivated JET staff to publish similar work [3].

Tonio also presented a paper on tritium and vacuum components at the SOFT conference last fall [4]. More recently, Tonio has completed a manuscript for a report on failure rates of the Joint European Torus (JET) heating, magnet, and neutral beam injector (NBI) power supplies, and the NBI equipment (report ENEA FUS-TN-SA-SE-R-121, to be published). There were over 2,150 power supply failure reports in the JET database from 1997-2003. The data analysis effort required 2,000 person-hours of effort to classify the data and another 500 person-hours to reduce the data. The neutral beams exhibited a very classic “burn-in” curve, the first 3.5 years showed a steep failure rate and after that time the failure rate became constant (i.e., the bottom of the bathtub curve). Therefore, only the data after the first 3.5 years was used for analysis of the constant-value failure rates. The results show that there is, on average, one failure for every 11 hours of NBI operations. The failures vary in severity, but it is clear that the NBI systems require frequent visits. The report manuscript is undergoing review by JET Operations personnel and the European Fusion Development Agreement (EFDA) JET Close Support Unit (CSU) prior to final publication. Tonio’s future plan is to examine the JET plasma heating system (ICRH and LHCD) components. He was asked if he would look for any documentation of erosion dust causing difficulties, such as short circuiting, with the heating antennas or grilles. Tonio stated that most of the failure reports do not carry that level of detail, but that he would look for such information and document anything he found.

Lee Cadwallader presented the latest US work, including a few results from a tritium failure rate comparison paper presented last fall [5]. More recent work in progress dwells on reliability analysis of DIII-D power supplies [6]. The DIII-D results will be compared to Tonio's JET results and all of those data will be placed in the database. The other aspect of the US work is industrial safety of fusion workers [7]. This study of worker 'conventional' safety parallels the ORE work, to feed forward the operating experiences of fusion facilities to ITER so that the ITER staff has the best information available to monitor and plan for worker safety. There were several possible choices for another system to analyze from DIII-D, including diagnostics or NBI, and possibly reviewing Tore Supra's in-vessel cooling experiences. For generic data, the most relevant work would be updating the cryogenic system data report from 1991. Since Professor Dies is attempting to gain access to Tore Supra data, especially the Tore Supra cryoplant data, the most promising work for the US is to survey the DIII-D diagnostics for vacuum safety, operability, and worker safety.

The next speaker was Dr. Ray Watkins, who was accompanied by Dr. Garry Voss, both from the Mega Amp Spherical Tokamak (MAST). Dr. Watkins discussed MAST use of reliability and availability data, which they track for each operating campaign. MAST uses Process Maps to track all work on the machine. Process Maps are similar to 'critical path methods', Gantt task scheduling charts, and 'program evaluation review technique' charts that are widely used in project management. MAST defines maintenance tasks and measures maintenance effectiveness using the Process Maps. Similar to other tokamaks, the basic measures of maintenance effectiveness are machine availability and reliability. Availability of MAST is defined as:

A = (time planned for MAST operation – delays) / (time planned for MAST operation)

Reliability of MAST is defined as:

R = (completed shots in a given time period) / (all shots operated in a given time period)

where a completed shot is a technically complete shot, which is not necessarily a completed shot that also pleases the physicists. A completed shot did, however, operate all equipment that was scheduled to operate in the shot plan and collect all the necessary plasma data. Dr. Watkins uses a Microsoft Access database to track delays and lost shots. They analyze the data and feed their results back to the maintenance planners and to the maintenance training staff. The Access database allows many ways to sort the collected data. The Engineer in Charge of the control room usually enters the data into the database. Data from each operating campaign is analyzed and reported, and the MAST availability and reliability updates are given at the weekly operations coordination meeting. This update allows the MAST staff to make corrections during the course of the operating campaign, so situations do not get worse as the campaign continues.

After lunch, Dr. Juergen Rapp, the Head of Operations in the EFDA JET CSU, visited our meeting. Tonio Pinna discussed the work that has been completed on JET power supplies and neutral beams, and Professor Dies remarked that he had contacted Tore Supra about data on their cryogenics system, but had not received an answer yet. Then Mr. Izquierdo began his presentation about the work he has performed on the database structure and taxonomy. The database currently uses Lotus Notes software, which is part of a site license at ENEA Frascati. They are switching over to use the MySQL software, which is a popular web-based database, for easier access and ease of use. Mr. Izquierdo restructured the component taxonomy of the database and used the IAEA TECDOC 478 [8] as the basis for the new taxonomy. This document has long been a guide for our work in the data harvesting side of the task and has the approval of task participants. Mr. Izquierdo noted that as more fusion-specific data become available, there will not be any need for component data decomposition to finer classifications because the data will be fusion-specific. In the component classification scheme, the database is now quasi-standard (similar to the IAEA database), and our database is self-consistent, hierarchical, and flexible. There are 106 failure modes listed thus far, in three families of components (mechanical, electrical, and instrumentation & control). Thus far, there are 25 component types listed in the database. The database is partitioned into two parts, user data and common data. User data has been entered by users and must be validated before it can be moved to the common data set. The common data set contains the 'finished' failure rate data records that any database user can access for their safety or reliability needs. There are currently ~500 data records in the user side of the database that await review and approval to move to the common side of the database. Mr. Izquierdo is presenting a paper on the database at the ISFNT7 meeting [9].

Mr. Izquierdo and Professor Dies plan to analyze the TJ-II Stellarator data, much like Tonio has done with the FTU and JET data, and Lee has done with DIII-D data. The TJ-II stellarator machine is operated by the Centro de Investigaciones Energeticas, MedoAmbientales y Technologicas (CIEMAT), which is Spain's Research Center for Energy, Environment and Technology. The TJ-II is located in Madrid. The TJ-II has a major radius of 1.5-m and 1 Tesla copper magnet coils; the machine had its first plasma in December 1997. Professor Dies has also proposed that he perform a data collection and analysis of Tore Supra data, but has not received a reply from the Tore Supra team.

Dr. Rapp discussed with us the JET Close Support Unit (CSU) point of view. If the JET machine loses a pulse, that is, the machine was ready to pulse, initiated a pulse and for whatever reason the pulse was not a success, then the customer is displeased. A lost pulse is a lost resource and an expense that increases the cost of successful pulses. About half of all JET pulses are relevant to physics and the other half of the pulses are not good – heating systems fail, data recorders fail, etc. An improper pulse could be the result of a human error (selecting the wrong power, the wrong power coupling, or some other human or scientific error). The CSU looks for bottlenecks to the process of pulsing, not for individual component faults. In the end, Tonio's detailed studies of component failure rates and CSU investigations for JET bottlenecks should merge to show components that are faulted, either mechanically or by human error. For fusion research, the fusion community needs to know if components are failing because they are at the state-of-the-art or forefront of technology and we must tolerate failures (and replacing the components as needed), or if it was a human error that caused a component to fault. After this discussion, Dr. Rapp had to take his leave to attend another meeting.

Task participants discussed some recent data requests and uses. The Wendelstein 7-X stellarator team is considering initiating a reliability and availability study. They have contacted Tonio about trading data. The CEA team writing the Rapport Preliminaire de Surete (Preliminary Safety Report) for ITER at Cadarache [10] has contacted Tonio for ORE and some other fusion operating experience data. This is also true of the International Fusion Materials Irradiation Facility (IFMIF) design team. Tonio also stated that Sergio Ciattaglia and other machine operators have collaborated to write a paper on the historical availability of presently operating fusion experiments (JET, FTU, DIII-D, others) for publication at upcoming ISFNT7 meeting.

The task direction was discussed, and the two objectives will continue – we will continue to analyze tokamak and other fusion facility data while still harvesting 'generic' data from the literature that is pertinent to fusion equipment and systems. The JET data thus far is detailed enough to give good results and operating times are long enough to give constant value failure rates that are useful to safety and reliability studies.

Tonio Pinna volunteered to host the next task meeting at ENEA-Frascati in the Spring of 2007.

The following day we had tours of the JET and MAST experiments. JET has been down for new component installation, including a divertor and diagnostics, and should be operating again in June 2005. One of the diagnostics is an alpha particle detector that was constructed at the PPPL. The tentative plan for JET is to burn tritium in another Deuterium-Tritium Experiment run (DTE II), but not before 2008. With the machine down we were able to enter the torus hall. Our guide on the tours was Chris Warrick, a physicist and public relations liaison at Culham Science Centre. We also saw the full size mockup room used for planning and testing remote handling operations, and the remote handling operations room complete with numerous television screens and manipulator handles for a standing operator to perform remote tasks inside the JET vessel. We saw the beryllium clean room where in-vessel parts are taken for cleaning and refurbishing in a controlled environment. The room was obviously ventilation controlled and all floor and work surfaces in the room were covered with multiple layers of plastic sheeting to facilitate cleanup after parts handling.

MAST is a smaller machine than JET, with a major radius of ~1.5 m and 3 m in height, compared to JET at ~3 m in major radius and 4.2 m height. MAST can achieve ~ 1MA plasma current while JET can achieve 4.8 MA. MAST began operation in December 1999.

After the tours, task participants had lunch and we discussed energy issues and topics until each participant needed to meet a taxi. Everyone discussed the current topics of interest, nuclear fission renewal, environmentally benign electricity production, hydrogen energy, and use of hydrogen in automobiles. The meeting was adjourned just after lunch. Meeting minutes, presentations, and photos will be available at the web site http://nuclear.inl.gov/fusionsafety/ and use the meetings link.

References

[1] M. Yamada, T. Yamanishi, W. Shu, T. Suzuki, H. Nakamura, Y. Kawamura, Y. Iwai, K. Kobayashi, K. Isobe, and M. Nishi, "Operation Results on Safety Systems of the Tritium Process Laboratory of the Japan Atomic Energy Research Institute," Fusion Science and Technology, 41 (2002) 593-597.

[2] T. Pinna, A. Natalizio, J. Levine, "TFTR Occupational Radiation Exposure Data Collection and Analysis," presented at the 23rd Symposium on Fusion Technology, Venice, Italy, 20-24 September 2004.

[3] P. Bharat, A. Natalizio, M. T. Porfiri, "Collection and Analysis of Occupational Radiation Exposure Data Related to JET Operations," presented at the 23rd Symposium on Fusion Technology, Venice, Italy, 20-24 September 2004.

[4] S. Ciattaglia, T. Pinna, G. Cambi, A Lo Bue, S. Knipe, J. Orchard, R. Pearce, U. Besserer, "Component Failure Data Collection and Analysis from JET and TLK Operating Experience," presented at the 23rd Symposium on Fusion Technology, Venice, Italy, 20-24 September 2004.

[5] L. C. Cadwallader, "Comparison of Tritium Component Failure Rates", presented at the 16th Topical Meeting on the Technology of Fusion Energy, Madison, Wisconsin, September 14-16, 2004.

[6] L. C. Cadwallader and P. I. Petersen, "Reliability Estimates of Power Supplies," abstract submitted to the 21st Symposium on Fusion Engineering, September 26-29, 2005, Knoxville, Tennessee.

[7] L. C. Cadwallader, Occupational Safety Review of High Technology Facilities, INEEL/EXT-05-02616, January 2005.

[8] Component Reliability Data for Use in Probabilistic Safety Assessment, IAEA TECDOC-478, International Atomic Energy Agency, Vienna, 1988.

[9] T. Pinna, J. Izquierdo, M. T. Porfiri, J. Dies, "Fusion Component Failure Rate Database (FCFR-DB)," to be presented at the 7th International Symposium on Fusion Nuclear Technology, Tokyo, Japan, 22-27 May, 2005.

[10] G. Marbach, J. Jacquinot, N. Taylor, "ITER at Cadarache: An Example of Licensing a Fusion Facility," Fusion Science and Technology, 44 (2003) 251-255.

Meeting Attendees:

Dr. Neill Taylor neill.taylor@ukaea.org.uk	UKAEA Fusion Culham Science Centre Abingdon Oxfordshire OX14 3DB United Kingdom
Professor Javier Dies Javier.Dies@upc.es	Universitat Politecnica de Catalunya Director of the Fusion Energy Engineering Laboratory Escola Tecnica Superior d'Enginyeria Industrial Avda. Diagonal, 647, Pavello C E-08028 Barcelona Spain
Mr. Jesus Izquierdo Villena jesus.izquierdo@upc.es	Universitat Politecnica de Catalunya Fusion Energy Engineering Laboratory Escola Tecnica Superior d'Enginyeria Industrial Avda. Diagonal, 647, Pavello C E-08028 Barcelona Spain
Dr. Tonio Pinna pinna@frascati.enea.it	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente Thermonuclear Fusion Division Via Enrico Fermi 45 I-00044 Frascati, Rome Italy
Dr. J. Ray Watkins Ray.Watkins@ukaea.org.uk	MAST Operations Unit Culham Science Centre Abingdon Oxfordshire OX14 3DB United Kingdom
Dr. Garry M. Voss Garry.Voss@ukaea.org.uk	New Concepts Group Culham Science Centre Abingdon Oxfordshire OX14 3DB United Kingdom
Dr. Juergen Rapp juergen.rapp@jet.efda.org	Head of Operations, EFDA JET CSU Culham Science Centre Building K1 Abingdon Oxfordshire OX14 3DB United Kingdom
Mr. Lee Cadwallader Lee.Cadwallader@inl.gov	Fusion Safety Program Idaho National Laboratory PO Box 1625 Idaho Falls, ID 83415-3860 United States

Task 5 of the IEA Cooperative Agreement on
Environment, Safety and Economic Aspects of Fusion Power
Meeting on Failure Data for Fusion Components
Culham Science Centre, UK, 5-6 Avril, 2005

Contribution from Mohamed Eid and Luciano Giancarli
CEA/DEN, Saclay, F-91191 Gif sur Yvette Cedex, France

This is a succinct monitoring report on some activities related to *Components Failure and Reliability Modeling* conducted in the CEA/DEN/DM2S. The major part of the activity is conducted in support to Fission Reactor (present & future) Technology. These activities are mainly R&D in Components Failure & Reliability modeling. Still, a minor part of these activities can be immediately used in the Fusion Components Failure & Reliability field. Some tasks have already been identified and proposed in support of the design activities for the Helium-Cooled Lithium Lead (HCLL) blanket both for DEMO and the commercial power reactor (in the Power Plant Conceptual Studies framework) but no progress to monitor in FY-2003 and FY-2004.

Regarding R&D activities relevant to fusion components, I can mention the following activities. Within a Ph.D. research work that I co-direct, we are developing a stochastic model describing different mechanisms of failure in the case of Vessel Structures. Fatigue, rupture and irradiation mechanisms are considered in modeling the rupture of a vessel operating under certain loading conditions of temperature and pressure. The distribution of initial flaws and cracks detection probabilities are integrated in the model as well. For each failure mechanism, the model applies a Markovian or semi-Markovian scholastic modeling procedure. The coupling between different failure mode and the spatial conditions on the vessel is believed to be achieved using Monte-Carlo sampling. We are not yet at this coupling phase of the work.

A particular interest is paid to the effect of neutron irradiation on the structure failure. Some already existing models allow us to correlate neutron fluence and toughness for a given material. However, experimental measurements on irradiated samples are rare and in some case lacking. Accordingly, we are being interested in developing some statistical schemes to improve the quality of the correlations (models) using few experimental measurements. At the moment, we are testing a method to fit "toughness" using 3-parameters Weibull distributions. The quality of the fitting is assessed using Monte-Carlo simulation. This work is directly extended to fusion structure failure modeling using the appropriate neutron fluence.

No progress to monitor regarding Tore Supra Failure data collection and treatment.

If I should give a recommendation based on my past 2 years activities in structure failure stochastic modeling, I would recommend including toughness data and toughness-neutron-irradiation data in the database.

mohamed.eid@cea.fr and giancarli@aquilon.cea.fr